g factor of few-electron highly charged ions *

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The g factor of highly charged ions is an excellent instrument for probing bound-state QED effects in the presence of a magnetic field, and, moreover, gives access to an accurate determination of fundamental physical constants and nuclear parameters. Few-electron ions are of particular interest: On the one hand, apart from to one-electron QED effects they provide an excellent possibility to probe also many-electron QED corrections. On the other hand, simultaneous investigations of one- and few-electron ions allow us to construct specific differences, where the uncertainty originating from the lack of knowledge of the nuclear properties can be almost eliminated. Studying of a specific difference of the g factors of H- and B-like ions [1] can provide an independent determination of the fine structure constant in the domain of strong external field.

The high-precision measurement of the g factor has been recently accomplished for Li-like $^{28}\mathrm{Si}^{11+}$ [2]. The measurement for B-like $^{40}\mathrm{Ar}^{13+}$ is already in preparation in the framework of the ARTEMIS project [3]. Here we report on recent progress in the theoretical predictions for these systems.

The theoretical contributions to the g factor of Li-like ions can be split into one-electron and many-electron parts, respectively. The former are similar to the corresponding corrections to the g factor in H-like ions. The latter, which define the difference between the g factors of H- and Li-like ions, are mainly due to screened QED-radiative and the interelectronic-interaction corrections. Until now, the interelectronic-interaction contributions have mainly determined the total theoretical uncertainty of the g factor of Li-like ions for all values of Z. Recently, we have performed the rigorous QED evaluation of the two-photon exchange corrections to the g factor [2, 4], and, thus, improved the total theoretical accuracy for the g factor of $^{28}\mathrm{Si}^{11+}$ by almost a factor of 2. A comparison of the experimental value $g_{\rm exp}[2s] = 2.000\,889\,888\,9(21)$ with the corresponding theoretical prediction $g_{\rm th}[2s] = 2.000\,889\,909(51)$ allows to probe the two-photon exchange correction on a level of about 1%. This provides the most stringent test of many-electron QED effects in the presence of a magnetic field.

The ARTEMIS project will implement the laser-microwave double resonance spectroscopy to measure with ppb accuracy the Zeeman splittings of both ground state $(1s)^2\,(2s)^2\,2p_{1/2}$ and first excited state $(1s)^2\,(2s)^2\,2p_{3/2}$ in boron-like argon [3]. Recently, we have performed accurate QED calculations of the g factor of these states [5]. The $1/Z$-term of the interelectronic interaction is calculated within the rigorous QED approach. For the ground state the higher-order contributions are evaluated within the large-scale configuration-interaction method with the Dirac-Fock and Dirac-Fock-Sturm basis functions (CI-DFS). The one-loop self-energy correction for P_J-states is calculated employing the Kohn-Sham potential, that partly takes into account the screening effect. The higher-order (two-loop) QED effects are accounted for to zeroth order in αZ. The recoil correction is evaluated to first order in m/M, also with the Kohn-Sham screening potential. The present results $g_{\rm th}[2p_{1/2}] = 0.663\,647(1)$ and $g_{\rm th}[2p_{3/2}] = 1.332\,285(3)$ are in agreement with those reported in Ref. [6] and are by order of magnitude more precise.

We also considered the effects of second- and third-order in the magnetic field, which can be expressed in the following way: $\Delta E_A^{(2)}(B) = g_J^{(2)}(M_J)(\mu_0 B)^2/(mc^2)$ and $\Delta E_A^{(3)}(B) = g_J^{(3)}(M_J)(\mu_0 B)^3/(mc^2)^2$, where μ_0 is the Bohr magneton and m is the electron mass. Accordingly, the results for $g_J^{(2)}$ and $g_J^{(3)}$ for B-like Ar are obtained as:

$$
\begin{aligned}
g_{1/2}^{(2)}(\pm 1/2) &= -39.5\times 10^3, & g_{1/2}^{(3)}(\pm 1/2) &= \pm 2.5\times 10^9,\\
g_{3/2}^{(2)}(\pm 1/2) &= 41.0\times 10^3, & g_{3/2}^{(3)}(\pm 1/2) &= \mp 2.5\times 10^9,\\
g_{3/2}^{(2)}(\pm 3/2) &= 1.0\times 10^3, & g_{3/2}^{(3)}(\pm 3/2) &= \mp 5.7\times 10^3.
\end{aligned}
$$

The ARTEMIS experimental setup implies the presence of a magnetic field of about 7 Tesla. This leads to the relative contribution of the quadratic effect $|\Delta E_A^{(2)}/\Delta E_A^{(1)}| = 0.9\times 10^{-4}$ for the $2p_{1/2}$ state and 0.5×10^{-4} for the $2p_{3/2}$ state. The relative contribution of the cubic effect yields $|\Delta E_A^{(3)}/\Delta E_A^{(1)}| = 4.7\times 10^{-9}$ for the $2p_{1/2}$ state and 2.3×10^{-9} for the $2p_{3/2}$ state. Therefore, the second- and third-order contributions can clearly be disregarded at the anticipated ppb-level of accuracy. The above results are closely related to recent experimental investigations [3], where details on the measurement procedure and the identification of higher-order effects can be found.

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